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13. ABSTRACT (Maximum 200 words)

The cold frontal event of 20-21 February 1992 that occurred in a densely instrumented observational domain during the Storm-scale Operational and Research Meteorology-Fronts Experiment Systems Test (STORM-FEST) was examined. Data were analyzed and the observed event was compared to a theoretical model that contains the basic physical mechanisms of dry and inviscid frontogenesis. The actual frontal evolution above the boundary layer (400-500m) compared well with the model predictions, but not in the boundary layer itself. The source of the discrepancy is shown to be associated with frictional retardation near the ground and the omnipresent inertial oscillations revealed in both surface and wind profiler data. These results were presented in a Ph.D thesis (May 1995) at the University of Colorado by Vern Ostdiek.

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Final Report

Front-Boundry Layer Models from

STORM-FEST Observations

1 June 1993–31 August 1995

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1.0 Executive summary

1.1 Objectives

This grant (F49620-93-1-0416, Amend. P0001), which was initiated on 1 June 1993, represents an AASERT grant to support the Ph.D. thesis research of Vern Ostdiek in the Astrophysical, Planetary and Atmospheric Sciences Department of the University of Colorado in Boulder.

The objectives were to:

1. Collect and analyze observational data for the front that passed into the Storm-scale Operational Research Meteorology–Fronts Experiment and Systems Test (STORM-FEST) array during the period 20-21 February 1992.
2. Compare the frontal characteristics to a theoretical model of a front produced by a deformation wind field.
3. Compare the boundary layer processess that occurred in association with this front with theoretical models of motions in nightime neutrally stratified boundary layers over relatively level terrain.

1.2 Status of effort

Dr. Ostdiek completed work on his thesis, and was awarded the Ph.D. degree by the University of Colorado on 12 May 1995. Both objectives 1) and 2) were completed and this work appeared in the thesis [Ostdiek (1995)] and in an article in the Journal of the Atmospheric Sciences (Ostdiek and Blumen, 1995). The majority of work on objective 3) was also completed, and appears in the thesis. The final part of the theoretical model comparisons are, however, not completed. Dr. Ostdiek and the P.I., W. Blumen, are presently completing this work, and expect to submit it for publication during the late fall of 1995. The details are provided in section 2.0.

1.3 Accomplishments

The event of 20-21 February 1992 represented a case of frontogenesis produced by a deformation wind field acting on a relatively weak temperature gradient. The isotherms are essentially aligned with the deformation axis (see Figure 1 a,b). This is a classic case of deformation frontogenisis explored extensively in theoretical and numerical models, but apparently there has not been observational verification of the model predictions until now. The observed case of low-level frontogenesis was compared to the Hoskins and Bretherton (1972) model for inviscid flow, and quantitative comparisons between theory and observation show very satisfactory agreement, at least above the nighttime boundary layer of 400-500 meter depth.

Analyses of the boundary layer data from the surface reports and boundary layer wind profilers show that low-level jets, with speeds of 12-13 m/s occur at several stations near

the front. The peak speeds occur at the top of the boundary layer, and the explanation for its occurrence seems to be the mechanism provided by Blackadar (1957) and Thorpe and Guymer (1977). This mechanism relies on the occurrence of inertial oscillations in the boundary layer, seemingly unaffected by viscous or turbulent processes, that reinforce the existing steady flow essentially balanced by pressure gradient forces. There are some differences between the observed case and the prototype models that have been developed, e.g., absence of a shallow surface inversion. The theory is being modified to explain these discrepancies.

The particular value of this research is associated with quantitative evaluation of both frontal and boundary layer models from a unique data set available from the STORM-FEST observational program (see Figure 2 a,b). The data provided by National Weather Service surface and upper air networks, as well as special observations from the STORM-FEST network, permit evaluation of model predictions on spatial and temporal scales that have not been possible in the past. This is considered to be the principal result of this research effort. Further, these model evaluations show some model limitations that need to be addressed. In particular, existing theoretical models of frontogenesis do not employ boundary layer dynamics in their description, e.g., the Hoskins-Bretherton (1972) model. Alternatively, numerical models often use either crude boundary layer parameterizations or sometimes detailed boundary layer dynamics. Lack of verification data has left open the question of the ability of various mesoscale models to produce relatively accurate predictions of low-level frontal characteristics. The present theoretical model of deformation frontogenesis will be modified in future work to incorporate the type of boundary layer processes observed during the event of 20-21 February 1992. This would be a step in the development of improved mesoscale predictions, particularly of internal waves, low-level jets and turbulence often observed in assosciation with fronts, that would be useful for both commercial and military flight operations.

1.4 Personnel involved in the research effort

Vern Ostdiek, graduate research assistant, Astrophysical, Planetary and Atmospheric Sciences Department, University of Colorado, Boulder, Colorado 80309.

William Blumen, professor and thesis supervisor, Astrophysical, Planetary, and Atmospheric Sciences Department, University of Colorado, Boulder, Colorado 80309.

1.5 Publications

Ostdiek, V., 1995: Deformation frontogenesis and related boundary layer processes: Observation and theory, Ph.D. Thesis, University of Colorado, Boulder, 164pp.

Ostdiek, V. and W. Blumen, 1995: Deformation frontogenesis: Observation and theory. J. Atmos. Sci., 52, 1487-1500.

1.6 Papers presented at conferences and seminars

1. American Meteorological Society Severe Storms Conference. St. Louis, Missouri, October 5, 1993.
2. American Meteorological Society Mesoscale Processes Conference, Portland, Oregon, July 20, 1994.
3. Reading University, United Kingdom seminar, May 31, 1995.
4. Cyclone Workshop, Pacific Grove, California, Presentation to be made December 7, 1995.

1.7 Data sources for STORM-FEST

All data used in the research that has been accomplished are available from the following sources:

1. STORM-FEST data available on mosaic: open URL http://www.ofps.ucar.edu
2. STORM-FEST cd, available from:

   Office Field Project Support
   UCAR, P.O. Box 3000
   3300 Mitchell Lane
   Boulder, CO 80301

2.0 Research on boundary layer processes

This section describes the work carried out on objective 3 in the Executive Summary, boundary layer processes that occurred in association with the frontal passage during 20–21 February 1992. Details of the frontal structure, evolution and theoretical analysis are covered by Ostdiek and Blumen (1995) and more extensively by Ostdiek (1995).

The most significant feature of the boundary layer, both before and after frontal passage, was the ubiquitous presence of inertial oscillations, particularly in the wind profiler data. These are wind oscillations with a period of 18.8 hours at 40° latitude. There were five 915 MHz wind profilers in the boundary layer array that provided data from approximately 167 m to about 3,000 m above the ground, about two dozen 403 MHz NOAA Demonstration wind profilers in the STORM-FEST domain providing data from approximately 320 m above the ground through the troposphere. The distribution of profilers is presented in Figure 2, with a typical example of the hourly data shown in Figure 1b. Data at 10 meters are available from surface observations.

The existence of an inertial oscillation in the Seneca boundary layer profiler (Figure 2b) data is strongly suggested in the vertical profiles presented in Figure 3a, where Topeka National Weather Service (NWS) and Seneca radiosonde data are also displayed. The confirmation that the inertial oscillation provides a relatively strong presence in these data is provided in Figure 3b, which displays hourly data from the Seneca profiler.

The profiler data from Seneca and other boundary layer profilers were analyzed by fitting those data to a steady and a time dependent wind profile. The time dependent variability was assumed to be a height dependent inertial oscillation (amplitude and phase vary with height). The steady state profile is still to be determined. The various models being used are 1) a barotropic Ekman profile, 2) a barotropic Ekman-Taylor solution, in which a shallow surface layer is matched to the Ekman layer, and 3) a baroclinic boundary layer profile. The various models represent models presented for the barotropic and baroclinic boundary layer by MacKay (1971) and by Bannon and Salem (1995). We have established that the barotropic Ekman profile does not fit any of the data, and are now examining the remaining cases.

The reason that the comparisons are being made between boundary layer models and the observations is to provide an explanation of why the inertial oscillations are so prevalent. Blackader (1957) and Thorpe and Guymer (1977), for example, have explained the presence of inertial oscillations in the planetary boundary layer by means of a decoupling between a relatively shallow surface layer and the atmosphere above. The surface layer, characterized by a nighttime radiation inversion, is very stable and suppresses vertical motion. Most of the frictional interaction with the ground is confined to this surface layer, allowing the inertial oscillation to proceed as an inviscid phenomenon.

The radiative inversion is totally absent on 20–21 February 1995, so that another explanation for the inertial oscillation is required. The lowest 400-500 meters of the atmosphere is neutrally stable. The attempt to fit the data to various boundary layer models will provide an explanation of why the inertial oscillation is effectively inviscid. Yet it is not obvious why the atmosphere would respond in this manner when boundary layer dissipation is not confined to a shallow surface layer.

3.0 Final remarks

Completion of the final phase of the present research, that is connected with objective 3, is expected by mid-fall 1995. A manuscript will be submitted to a meteorological journal for publication.

The most significant aspect of the present observations is the presence of time- dependent motions in the planetary boundary layer, in this case below about 500 m. The accepted theory of deformation frontogenesis, used by Ostdiek and Blumen (1995) and Ostdiek (1995), excludes boundary layer processes in its formulation. Yet comparison with observations and theoretical predictions is relatively satisfactory above the boundary layer. The discrepancies are mainly confined to the boundary layer. Future work will be devoted to providing a more complete frontogenesis model that takes account of physical processes that have been omitted in the semigeostrophic development.

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Bannon, P.R. and T.L. Salem, 1995: Aspects of the baroclinic boundary layer. J. Atmos. Sci., 52, 574–596.

Blackadar, A.K., 1957: Boundary layer wind maxima and their significance for the growth of nocturnal inversions. Bull. Amer. Meteorol. Soc., 38, 283-290.

Hoskins, B.J. and F.P. Bretherton, 1972: Atmospheric frontogenesis models: mathematical formulation and solution. J. Atmos. Sci., 29,11-37.

MacKay, K.P., 1971: Steady state hodographs in a baroclinic boundary layer. Boundary Layer Meteorol., 2, 161–168.

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Ostdiek, V. and W. Blumen, 1995: Deformation frontogenesis: Observation and theory. J. Atmos. Sci., 52, 1487–1500.

Thorpe, A.J. and T.H. Guymer, 1977: The nocturnal jet. Quart. J. Roy. Meteorol. Soc., 103, 633-653.

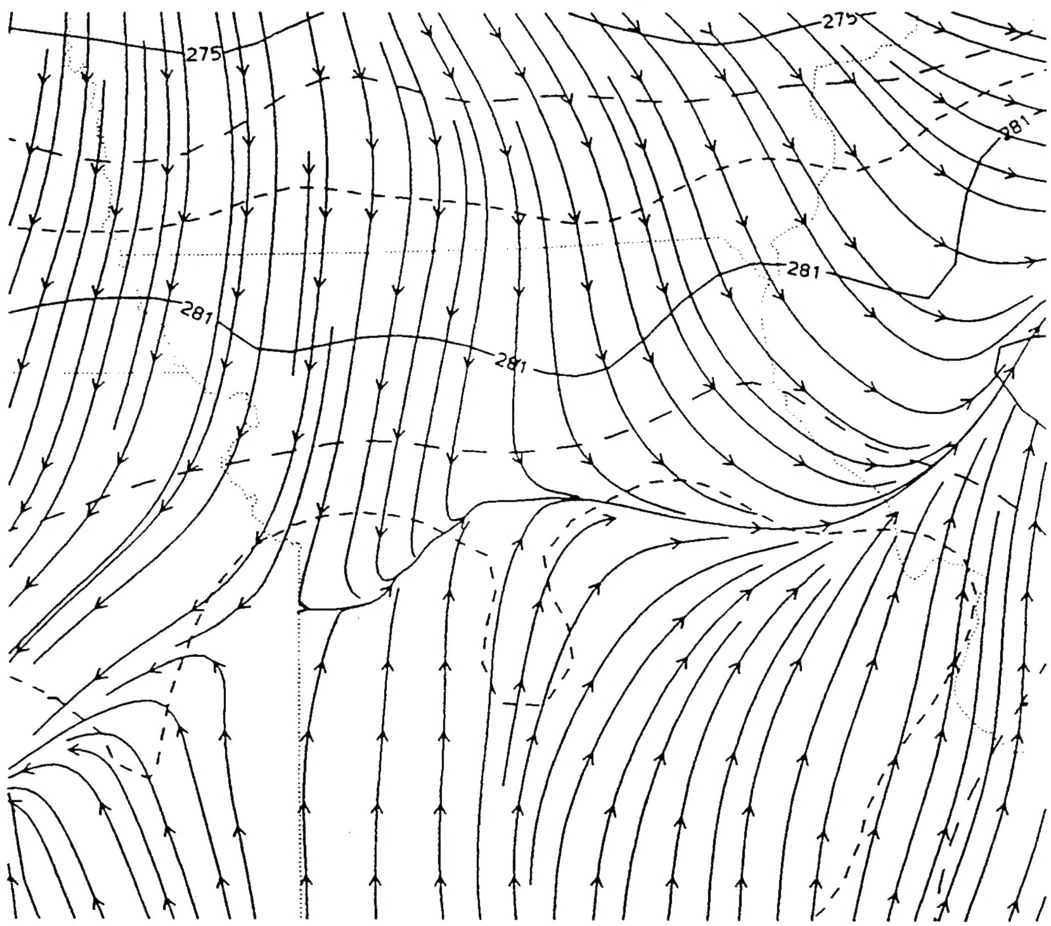


Figure 1a. Map showing hourly averaged surface potential temperature contours with overlay of streamlines for 2000 LST 20 February 1992. The dotted lines are state boundaries.

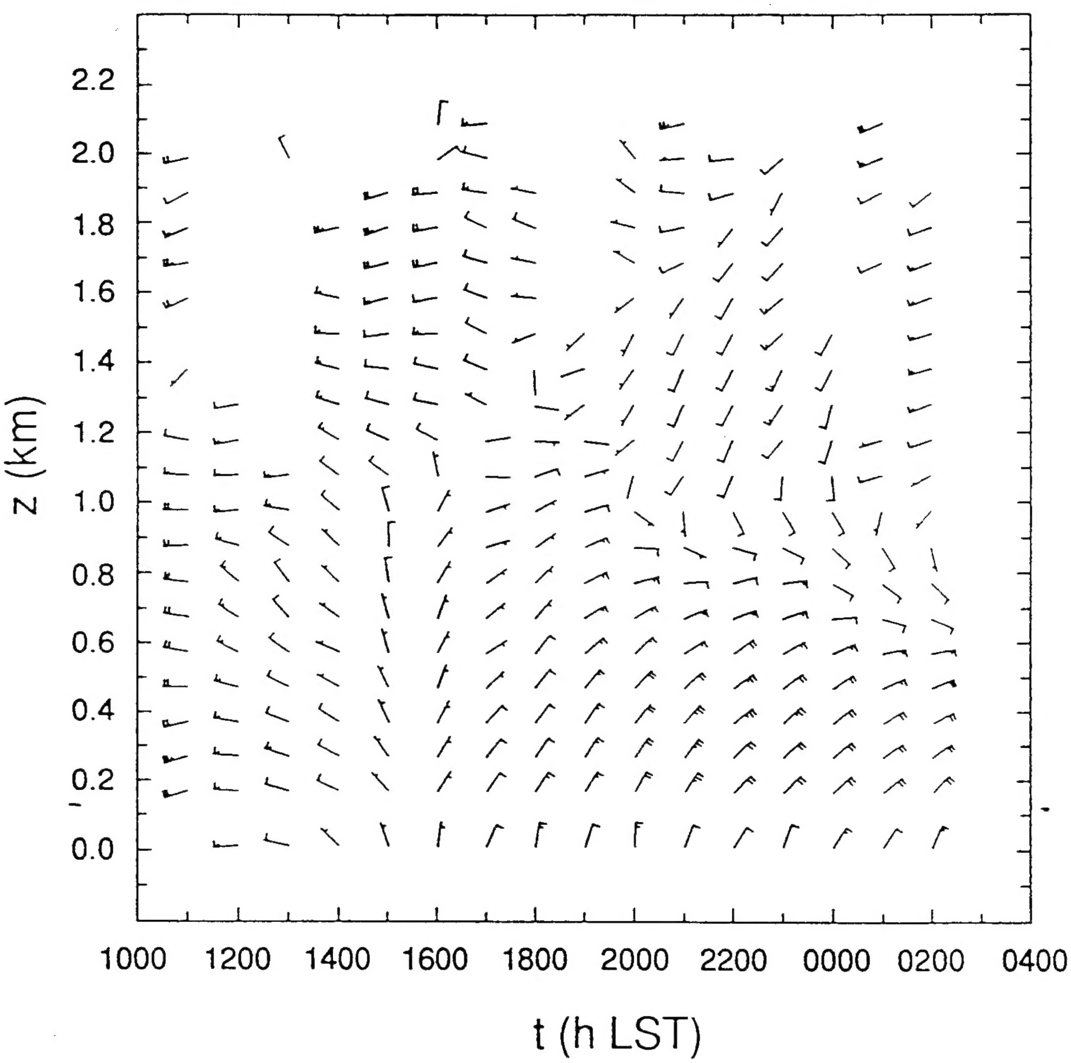


Figure 1b. Hourly averaged winds measured by the Seneca boundary layer profiler and collocated PAM 41, from 1100 LST on 20 February to 0200 LST on 21 February. Each half barb represents 5 knots ($\approx$ 2.5 m/s) and each full barb represents 10 knots ($\approx$ 5 m/s). The passage of the deformation flow is seen in the wind shift between 1400 and 1700 LST.

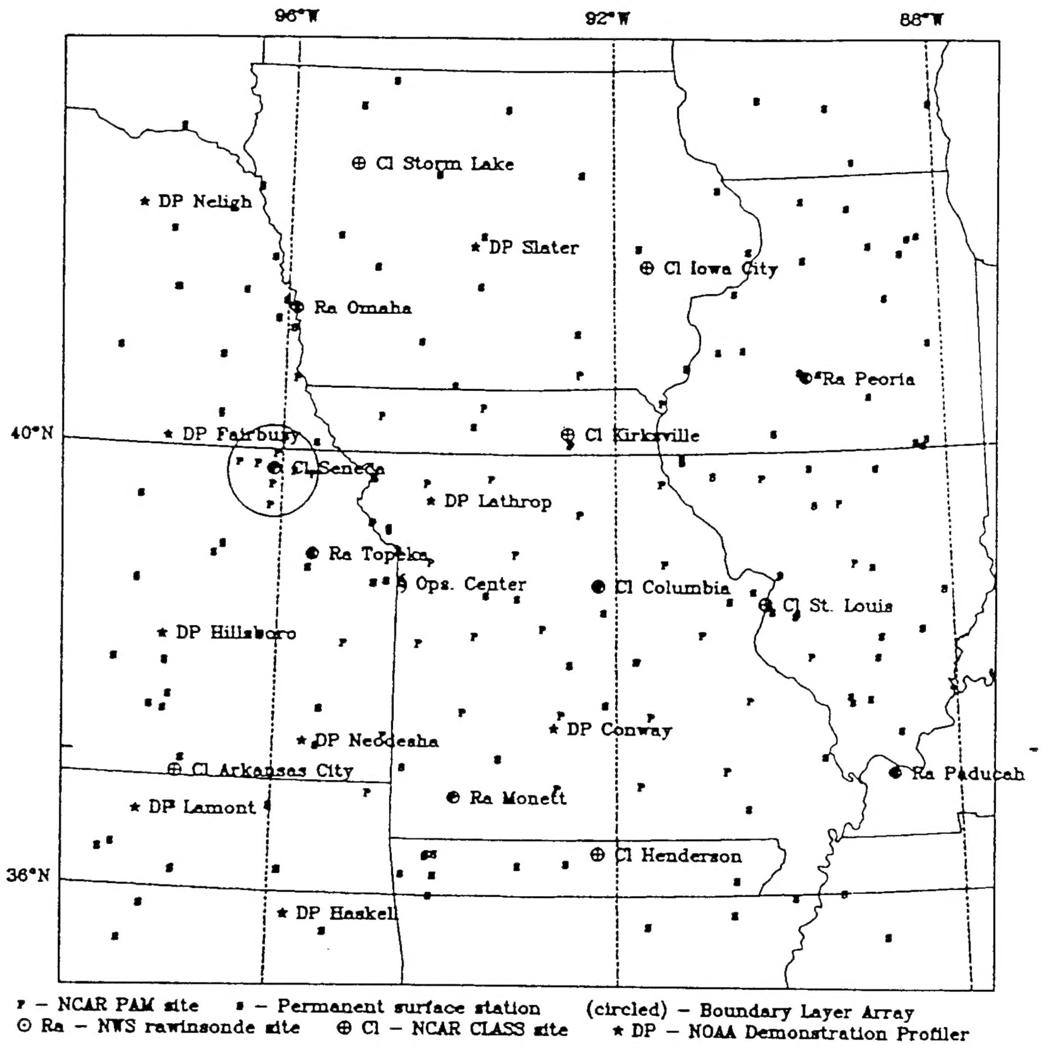
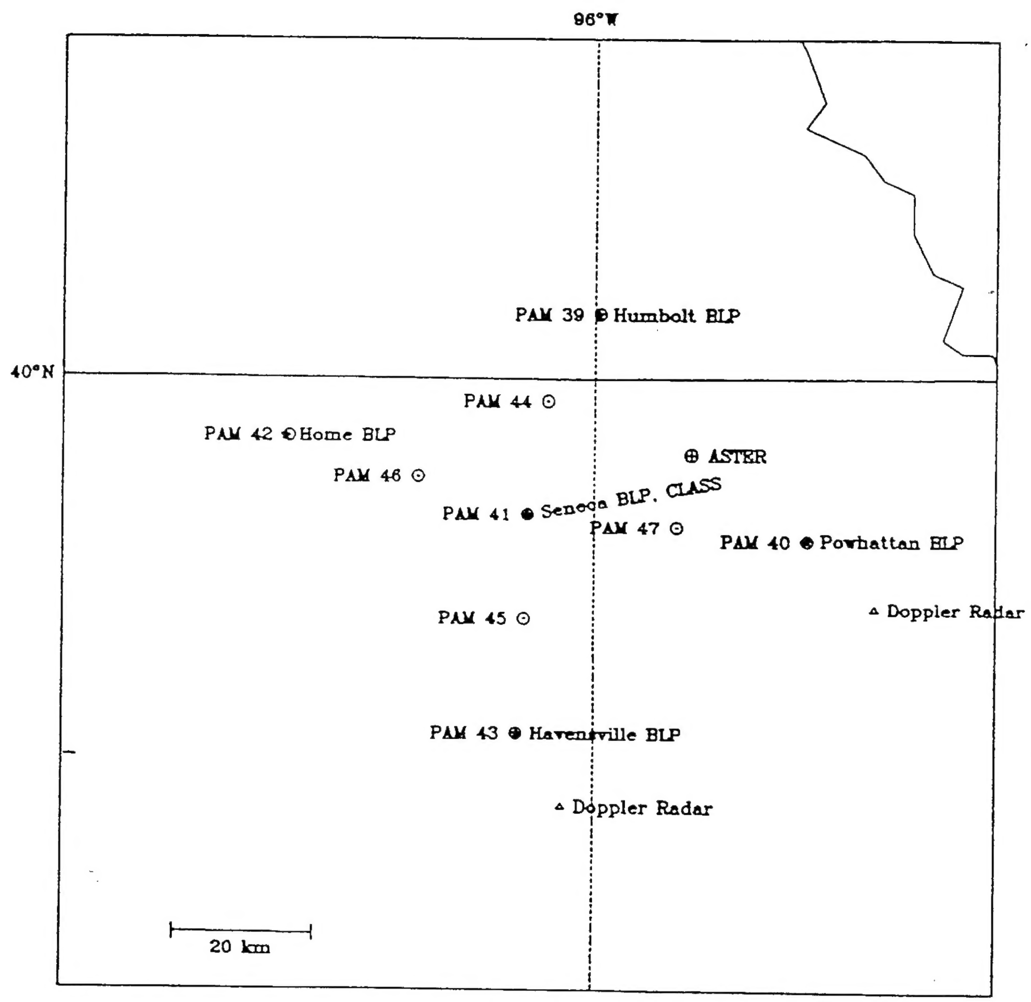
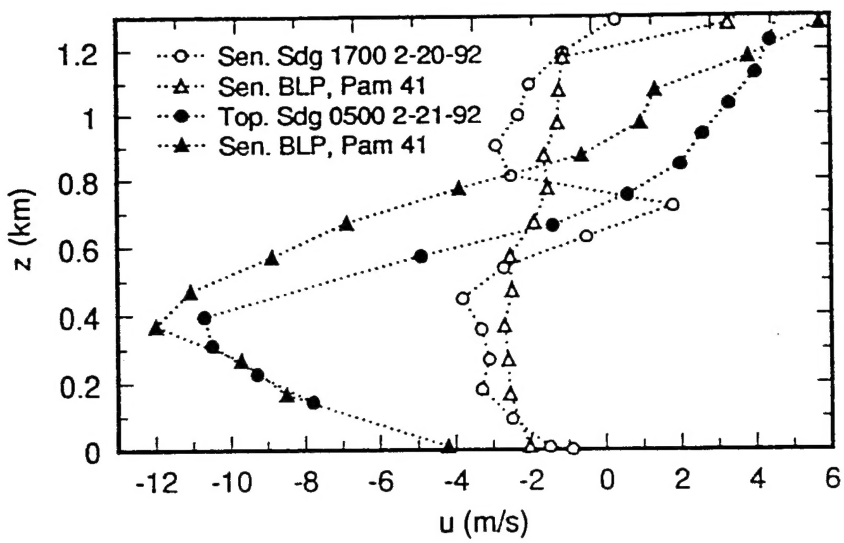


Figure 2a. Map of the Central United States showing STORM-FEST station locations. The Boundary Layer Array is in the circled region at left center.



BLP – Boundary Layer Research Wind Profiler

Figure 2b. Detailed map of instrument locations in the Boundary Layer Array (circled region in Figure 2a).



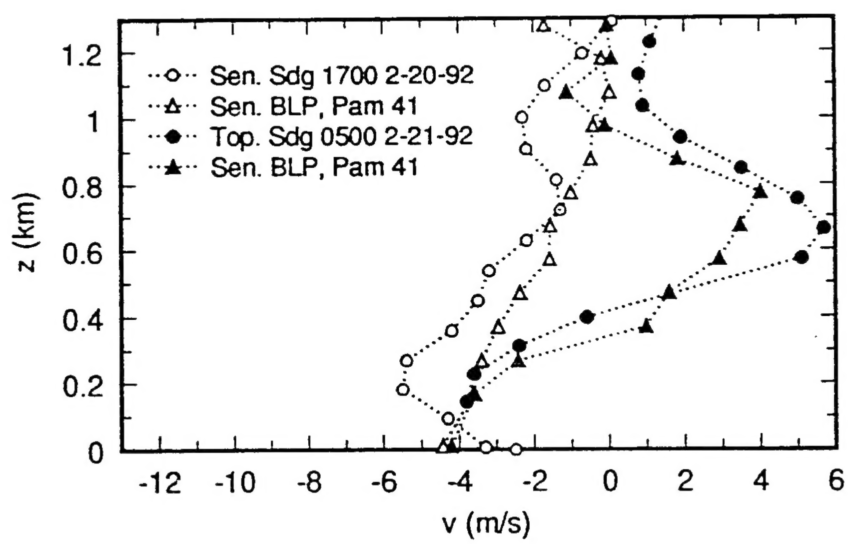


Figure 3a. Comparison of vertical profiles of zonal wind u (upper)and meridional wind v (lower) taken by the Seneca boundary layer profiler and nearest available soundings (Seneca CLASS sounding and Topeka NWS sounding). The two times, 1700 LST on 20 February and 0500 LST on 21 February, are near the beginning and near the end, respectively, of the period of inertial oscillation being discussed.

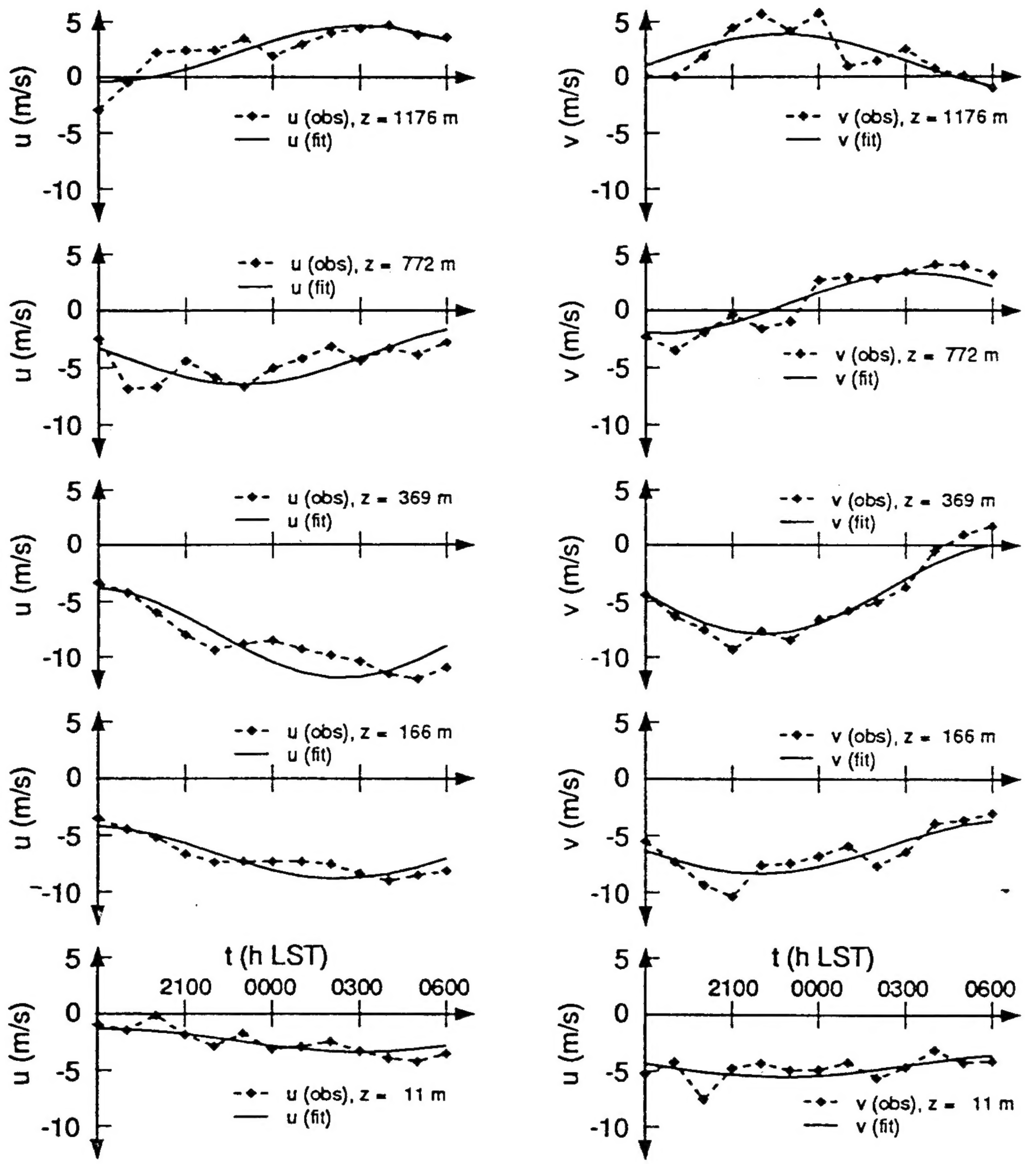


Figure 3b. Plots of observed and least-squares fit u (left) and v (right) versus time. From bottom to top: surface PAM station, lowest level of Seneca boundary layer profiler, level of jet maximum and largest-amplitude inertial oscillation, an intermediate upper level, and highest profiler level used.